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AN INVESTIGATION OF DAMAGED OR UNDAMAGED SMALL EARTH DAMS FOR IRRIGATION DURING THE 1983 NIHONKAI-CHUBU EARTHQUAKE

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SUMMARY

A total of 1129 data on damaged or undamaged small earth dams for irrigation in Aomori and Akita prefectures were investigated in 36 items by distributing relevant questionnaires. The dams were classified into three groups, such as heavy-damaged dams (A), light-damaged dams (B) and undamaged dams (C). The ratio A/(A+B+C) and (B+C)/(A+B+C) should be used to evaluate that a small earth dams for irrigation will be damaged or undamaged against a future earthquake. The investigation of not only damaged dams but also undamaged ones is indispensable to predict earthquake damage for the dam.

INTRODUCTION

There are about 250,000 small earth dams for irrigation in Japan whose roles are becoming increasingly more important in the agricultural engineering in recent years. If some dams suffer damage due to an earthquake, the surroundings will be seriously affected by the damage. The dams must be chosen to be reinforced against large magnitude earthquakes. Therefore, first of all, what kind of dams are susceptible to damage must be investigated. Conventionally, the method to clarify damage factors has been taken by particular investigation of damaged dams. However, the method can not explain factors of undamaged dams, that is to say, what kind of dams are not damageable. It is considered to be an effective method to make a complete survey of the state of pre-earthquake on damaged or undamaged dams in an area hit by a large magnitude earthquake and to analyze damage factors from significant differences between damaged and undamaged dams. The object in this paper is to investigate a great amount of information to discriminate between damaged and undamaged small earth dams for irrigation, which is used to analyze damage factors by the "Type II quantification analysis" (Refs. 1 and 2). From the point of view, the survey was made on damaged or undamaged dams due to the 1983 Nihonkai-chubu earthquake by distributing relevant questionnaires. The result obtained from the survey and the damage ratio are described in detail in this paper.

DAMAGED OR UNDAMAGED DATA

The range of survey is within a radius of about 150 km in Aomori and Akita prefectures and corresponds roughly to the region of JMA Intensity Scale V. A total of 1129 data on the small earth dams for irrigation were investigated in 36 items, such as the construction age, the type of dam, the height of dam, the

Table 1 Damaged or Undamaged Data

ITEM	CATEGORY	TOTAL	DAMAGED LEVEL			RATIO (%)			
			HEAVY A	LIGHT B	UNDAMAGED C	$\frac{A}{A+B+C}$	$\frac{B+C}{A+B+C}$	$\frac{A}{\Sigma A}$	$\frac{B+C}{\Sigma (B+C)}$
Construction Age	-1912	841	99	28	714	11.8	88.2	68.3	75.4
	1913-1952	231	36	4	191	15.6	84.4	24.8	19.8
	1953-1984	57	10	0	47	17.5	82.5	6.9	4.8
Type of Dam	uniform	1090	136	24	930	12.5	87.5	93.8	97.0
	other	39	9	8	22	23.1	76.9	6.2	3.0
Height of Dam (m)	0 - 5	664	75	18	571	11.3	88.7	51.7	59.9
	5 - 10	360	57	10	293	15.8	84.2	39.3	30.8
	10 - 15	67	9	1	57	13.4	86.6	6.2	5.9
	15 -	38	4	3	31	10.5	89.5	2.8	3.4
Crest Length (m)	0 - 50	407	32	6	369	7.9	92.1	22.1	38.1
	50 -100	442	60	11	371	13.6	86.4	41.4	38.8
	100 -	280	53	15	212	18.9	81.1	36.5	23.1
Crest Width (m)	0 - 3	412	26	4	382	6.3	93.7	17.9	39.2
	3 - 4	363	58	14	291	16.0	84.0	40.0	31.0
	4 -	354	61	14	279	17.2	82.8	42.1	29.8
$\frac{\text{Crest Width}}{\text{Height of Dam}}$	0.0-0.6	388	34	8	346	8.8	91.2	23.4	36.0
	0.6-1.0	403	71	12	320	17.6	82.4	49.0	33.7
	1.0-	338	40	12	286	11.8	88.2	27.6	30.3
Upstream Slope (Ratio of Horizontal to Vertical)	0.0-1.5	390	17	5	368	4.4	95.6	11.7	37.9
	1.5-2.0	346	35	7	304	10.1	89.9	24.2	31.6
	2.0-	393	93	20	280	23.7	76.3	64.1	30.5
Downstream Slope (Ratio of Horizontal to Vertical)	0.0-1.5	296	18	1	277	6.1	93.9	12.4	28.3
	1.5-2.0	492	64	11	417	13.0	87.0	44.1	43.5
	2.0-	341	63	20	258	18.5	81.5	43.5	28.2
TOTAL		1129	145	32	952	12.8	87.2	100.0	100.0

Table 1 Damaged or Undamaged Data (Continued)

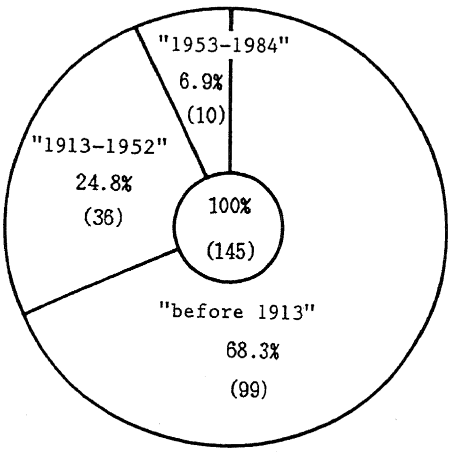
ITEM	CATEGORY	TOTAL	DAMAGED LEVEL			RATIO (%)			
			HEAVY A	LIGHT B	UNDAMAGED C	A / A+B+C	B+C / A+B+C	A / ΣA	B+C / Σ (B+C)
Geological Age of Substratum	Tertiary	461	29	5	427	6.3	93.7	20.0	43.9
	Diluvial	349	76	14	259	21.8	78.2	52.4	27.7
	Alluvial	319	40	13	266	12.5	87.5	27.6	28.4
Soil of Substratum	Rock	385	15	3	367	3.9	96.1	10.4	37.6
	Sand	129	35	15	79	27.1	72.9	24.1	9.6
	Clay	615	95	14	506	15.4	84.6	65.5	52.8
Material of Dam	Sand	87	25	6	56	28.7	71.3	17.2	6.3
	Clay	1042	120	26	896	11.5	88.5	82.8	93.7
Topography	Mountain	316	31	3	282	9.8	90.2	21.4	29.0
	Hill	243	21	2	220	8.6	91.4	14.5	22.6
	Tableland	269	55	18	196	20.4	79.6	37.9	21.7
	Fan Delta	301	38	9	254	12.6	87.4	26.2	26.7
Crest Settlement before Earthquake	Yes	108	37	8	63	34.3	65.7	25.5	7.2
	No	1021	108	24	889	10.6	89.4	74.5	92.8
Leakage of Water before Earthquake	Yes	245	35	8	202	14.3	85.7	24.1	21.3
	No	884	110	24	750	12.4	87.6	75.9	78.7
Epicentral Distance (km)	0-100	257	52	15	190	20.2	79.8	35.9	20.8
	100-120	351	63	2	286	17.9	82.1	43.4	29.3
	120-140	356	14	15	327	3.9	96.1	9.7	34.8
	140-	165	16	0	149	9.7	90.3	11.0	15.1
Water Level (Depth of Water / Height of Dam)	0.0-0.4	83	27	8	48	32.5	67.5	18.6	5.7
	0.4-0.7	480	79	20	381	16.5	83.5	54.5	40.7
	0.7-	566	39	4	523	6.9	93.1	26.9	53.6
TOTAL		1129	145	32	952	12.8	87.2	100.0	100.0

crest length, the crest width, the ratio of crest width to height of dam, the upstream slope, the downstream slope, the geological age of substratum, the soil of substratum, the material of dam, the topography, the crest settlement before the earthquake, the leakage of water before the earthquake, the epicentral distance, the water level and so on (Ref. 3). The dams were classified into three groups, such as heavy-damaged dams (A), light-damaged dams (B) and undamaged dams (C). The rank A, B and C mean "failure or its equivalent damage", "damage not to develop into rank A", and "no damage", respectively. The damage equivalent to failure was defined as follows. Those are (1) sliding of slope, (2) longitudinal crack more than 5 cm wide, (3) transverse crack, (4) crest settlement more than 30 cm and (5) leakage of water. The numbers of data in A, B and C were 145, 32 and 952, respectively. In this paper, the four types of ratio were investigated in detail, such as the ratio A/(A+B+C), (B+C)/(A+B+C), A/ΣA and (B+C)/Σ(B+C).

FOUR TYPES OF RATIO

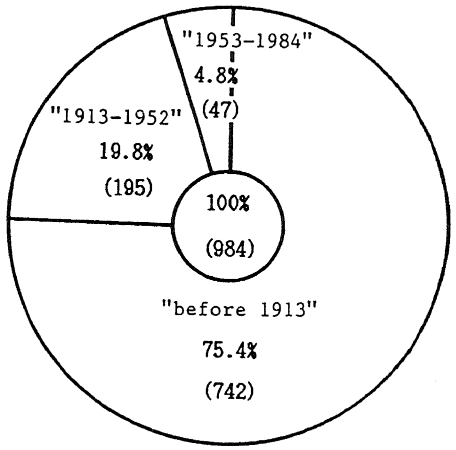
In this paper, the factor affecting the degree of damage is called "item" and an item is classified into some "categories". There are 36 items in the distributed questionnaire to collect the data of 1129 small earth dams for irrigation regarding to the 1983 Nihonkai-chubu earthquake. Table 1 shows the total number, the number of A, B and C, and the ratio of A/(A+B+C), (B+C)/(A+B+C), A/ΣA and (B+C)/Σ(B+C) in each category of 16 items as examples of 36 items. The A/(A+B+C) is the ratio of the number of heavy-damaged dams (A) to the sum of heavy-damaged dams (A), light-damaged dams (B) and undamaged dams (C) in each category. The (B+C)/(A+B+C) is the ratio of the number of (B+C) to the sum in each category. The A/ΣA is the ratio of the number of heavy-damaged dams (A) in each category to the total number of heavy-damaged dams ΣA. The (B+C)/Σ(B+C) is the ratio of the number of (B+C) in each category to the total number of Σ(B+C).

The ratio A/ΣA of the construction age in Table 1 is shown in Fig. 1. The ratio A/ΣA of "before 1913" is highest in Fig. 1, where the data of heavy-damaged dams are used only. According to the result in Fig. 1, it may be misunderstood



The number of the dams is written in ( )

Fig. 1 Heavy-Damaged Data A/ΣA

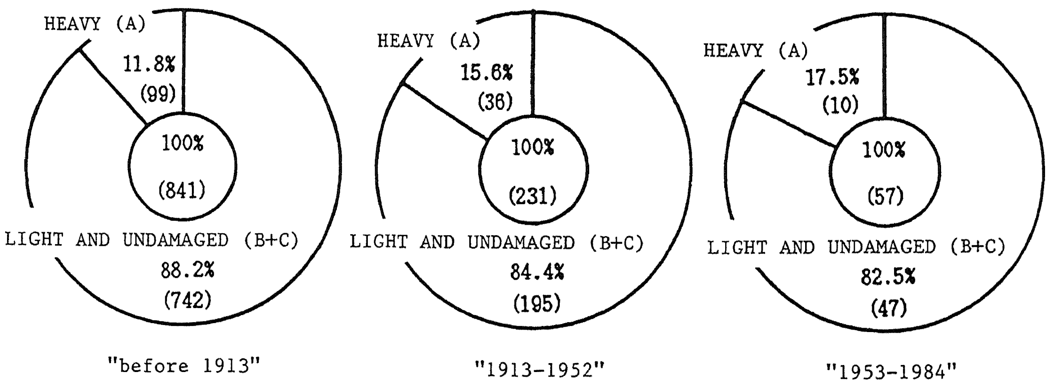


The number of the dams is written in ( )

Fig. 2 Light or Undamaged Data (B+C)/Σ(B+C) that the dams constructed before 1913 are the most dangerous ones among the three types of age. On the other hand, the ratio $(B+C)/\Sigma(B+C)$ of the construction age in Table 1 is shown in Fig. 2. The ratio $(B+C)/\Sigma(B+C)$ of "before 1913" is highest in Fig. 2, where the data of heavy-damaged dams are not used. According to the result in Fig. 2, it may be misunderstood that the dams constructed before 1913 are the most earthquake-resistant ones among those. The result in Fig. 1 is contradictory to that in Fig. 2. Generally, on the occasion of an investigation after a large magnitude earthquake, only damaged ones are investigated because of economy of time and in expenditures. If only damaged ones are investigated, the greatest care should be taken to avoid the above-mentioned misunderstanding. The ratio A/(A+B+C) and (B+C)/(A+B+C) of three categories in the construction age are shown in Fig. 3. According to Fig. 3, the ratio A/(A+B+C) in old age is lower than that in new age. It means that the dams constructed before 1913 are the most earthquake-resistant ones among those. And the ratio (B+C)/(A+B+C) in old age is higher than that in new age. It means the very same, too. The result obtained from the ratio A/(A+B+C) is compatible with that obtained from the ratio (B+C)/(A+B+C). Consequently, it is found that the dams constructed before 1913 are the most earthquake-resistant ones among the three types of age. The ratio A/(A+B+C) and (B+C)/(A+B+C) in Table 1 should be used to evaluate that a small earth dam for irrigation will be damaged or undamaged against a future earthquake. The investigation of not only damaged dams but also undamaged ones is indispensable to predict earthquake damage for a small earth dam for irrigation. Note that the above-mentioned misunderstanding is obtained from the investigation of damaged dams.

CONSIDERATION ACCORDING TO DAMAGE RATIO A/(A+B+C)

According to the ratio A/(A+B+C) in Table 1, the most dangerous dam is as follows. That is, (1) "Construction Age" is "1953-1984", (2) "Type of Dam" is not "uniform", (3) "Height of Dam (m)" is "5-10", (4) "Crest Length (m)" is "100-", (5) "Crest Width (m)" is "4-", (6) the ratio of "Crest Width to Height of Dam" is "0.6-1.0", (7) "Upstream Slope (Ratio of Horizontal to Vertical)" is "2.0-", (8) "Downstream Slope (Ratio of Horizontal to Vertical)" is "2.0-", (9) "Geological Age of Substratum" is "Diluvial", (10) "Soil of Substratum" is "Sand", (11) "Material of Dam" is "Sand", (12) "Topography" is "Tableland", (13) "Crest Settlement before Earthquake" is "Yes", (14) "Leakage of Water before Earthquake"



The number of the dams is written in ( )

Fig. 3 Damage Ratio A/(A+B+C)

is "Yes", (15) "Epicentral Distance (km)" is "0-120" and (16) "Water Level (Depth of Water / Height of Dam)" is "0.0-0.4". For example, the dam of the category "15-" in the item "Height of Dam (m)" is the most earthquake-resistant one. It is supposed that the result is due to construct such a high dam carefully. According to the result obtained from the both items "Upstream Slope" and "Downstream Slope", the dam of gentle slope is more dangerous than that of steep slope. Moreover, according to the result obtained from the item "Geological Age of Substratum", the dam constructed on the substratum of "Diluvial" is more dangerous than on that of "Alluvial". It is hard to understand the results from point of conventional view. However, as stated above, it is supposed that those results are due to construct a dam carefully under ill condition. An earthquake damage occurs generally caused by many factors that are complicatedly entangled together. It is difficult to grasp the relation between an earthquake damage and each factor even if relevant factors are individually analyzed. In other words, it may be not able to obtain the true result by only one item. Therefore, the factors analysis by the "Type II quantification analysis" was carried out in detail (Refs.1 and 2).

CONCLUSION

An investigation of 1129 damaged or undamaged small earth dams for irrigation in Aomori and Akita prefectures by the 1983 Nihonkai-chubu earthquake was carried out by distributing relevant questionnaires about 36 items. A great amount of information to discriminate between damaged or undamaged small earth dams for irrigation is investigated in detail. The ratio A/(A+B+C) and (B+C)/(A+B+C) should be used to evaluate that a dam will be damaged or undamaged against a future earthquake. The result obtained from the investigation of damaged dams is not always meaningful, and it may induce a misunderstanding. Consequently, the investigation of not only damaged dams but also undamaged ones is indispensable to predict earthquake damage for a dam (Refs. 1 and 2).

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